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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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STATEMENT

During the Apollo 5 mission, when the lunar module descent engine was fired for the second and third times, an out-of-phase indication was received from one of the two pairs of actuators that control the eight propellant shutoff valves. The indication was received after the descent engine was commanded from 10-percent thrust to full throttle. The indication slightly lagged an inflection point in the pressure/time curves for the oxidizer and fuel injector pressures and chamber pressure.

DISCUSSION

The engine pressures responded properly to the throttle command until, at approximately 70-percent chamber pressure, a plateau was noted in the indications of both injector pressures and chamber pressure (see fig. 1). Also, increases were noted in the oxidizer and fuel interface pressures. The out-of-phase signal could indicate that either the instrumentation malfunctioned or that one or two of the shutoff ball valves in the propulsion system moved from the open position.

A schematic of the shutoff ball valve system is shown in figure 2. The phase monitor consists of eight reed switches divided into two sets of four (A/B and C/D). Each set is wired into a bilevel event measurement which indicates whether the two actuators in each pair are both open or both closed. During the anomaly, the A/B event measurement changed state, indicating that one or two valves had moved from the open position, with the following possibilities:

a. One moved and could have closed completely.

b. Two moved, and one could have closed completely.

One possible explanation for the phasing anomaly is an electrical or instrumentation (reed switch) malfunction. Another possibility is a valve closure, or partial closure, because of hydraulic leaks in the pilot valve or the actuator cylinder. Each of the possible causes was investigated through analysis of potential sources of malfunction and through special tests. In addition, the reliability, quality control, and developmental test histories of the suspect components were examined.

Finally, checkout test procedures were examined to evaluate their adequacy. Some of the more significant possible causes are discussed in the following paragraphs.

Reed Switch Failure

The investigation disclosed that the reed switch was an unreliable device and was subject to installation problems that could cause malfunctions. However, none of the malfunctions were like the out-of-phase indication during the Apollo 5 mission. Most previous malfunctions had been failure of a valve-open indicator switch to change state when the valve was initially opened. However, this type of failure can be discounted as a cause of the anomaly, since the proper phase indication was received during the 10-percent thrust portion of all three firings and after the valves were closed (fig. 3). Further, the time from first movement of the throttle control to change of the phase indication was 299 and 291 milliseconds for the second and third firings, respectively; this repeatability demonstrates that the instrumentation indications were quite consistent.

The phasing monitor has been eliminated from LM-5 and subsequent vehicles.

Electromagnetic Interference Effects

The possibility of electromagnetic interference in the signal conditioner or in the PCM system was investigated and was subsequently eliminated as a possible cause of the anomaly. The signal conditioner was a package of twelve circuits in a subassembly. The out-of-phase event shared a PCM word with several other bits, and no off-nominal indications were noted in any of the other data using the same conditioner or PCM word. Specifically, the C/D valve indication shared the same conditioner and PCM word and was not affected.

Electrical System

The power source for the actuator pilot valves is common to all four, and each pilot valve has redundant power and return wires. A malfunction of the command signal or of the wiring up to the engine interface is precluded because all valves operated properly at shutdown and at 10-percent thrust.

The only possible electrical malfunction which could have caused the anomaly was an intermittent condition in the solenoid valve (i.e., broken wires making and breaking the circuit). However, because of the redundancy, a lead wire in each pair would have had to fail, one being completely separated and the other being in contact at 10-percent thrust but not during transition to full throttle. In that case, the ball poppet in the pilot valve would move from the vent seat and permit the actuator piston to partially or totally close.

A quality control problem, consisting of "birdcaging," poor solder joints, broken strands, and in one case a completely broken lead (fig. 4), was discovered in the wiring of some solenoid pilot valves. As a result of these discoveries, the solenoids were replaced on LM-3 and LM-4. The LM-1 solenoids were not inspected. Consequently, the conditions mentioned above may have existed.

System Pressures

All electrical circuits associated with the throttle actuator command voltages were reviewed, but no plausible failures that could explain the anomaly were discovered. An analysis was made to determine whether the flight pressure data could be utilized to discover the cause of the anomaly. Particular attention was directed to the pressure plateaus mentioned previously and to the spikes in the interface pressures, since these characteristics had not been noted during acceptance tests on the engine. However, subsequent analyses of the test data for other engines revealed that nitrogen-saturated propellants did cause similar plateaus.

Tests using helium-saturated propellants were conducted to determine how a valve closure during the throttle-up transient would affect chamber, injector, and interface pressures. The interface pressure did not rise, and while some plateaus in the chamber pressure were noted, they were not caused by a valve closure. The pressure transient from the Apollo 5 mission is compared with the test series in figure 5.

Flight data were used to investigate steady-state pressure drops in the feed system. When one of the four ball-valve actuators closes, the hydraulic resistance increases, and the pressure difference between the engine interface and the injector increases. This was demonstrated during the acceptance tests on the Apollo 5 engine. Calculated and actual values of pressure drop for oxidizer and fuel are:

	Pressure drop, psi	
	Oxidizer	Fuel
Flight data	14.5	92.0
Calculated		
Valve closed	17.0	93.7
Valve open	9.8	89.3

The calculated values were verified using the acceptance test data from the Apollo 5 engine. The results tend to substantiate valve closure but are not conclusive. The pressure data, including allowances for instrumentation errors, can be made to fit the analytical model which contains no valve failure. However, better fits were obtained for a valve closure, and the best fit was obtained for a partial valve closure.

If the ball poppet in the pilot valve moved from the seat, propellant would leak through the vent line, and actuator piston pressure would be reduced. If the combination of a normal pressure drop resulting from throttling and a pressure decrease caused by leakage reduced the actuator cavity pressure below approximately 100 psia, the valve would tend to close. Possible leakage mechanisms could have been a jammed poppet spring, debris, cracked valve seats, contamination, or freezing. However, leakage would have significantly increased the starting times of the engine and the operating times of the shutoff valves. The actual times were normal, thus tending to discount leakage.

CONCLUSIONS

The cause of the anomaly cannot be conclusively established, although the two most likely possibilities are either that an electrical circuit opened or shorted to cause the valve to close or that a reed switch malfunctioned under increased vibration with increasing throttle settings.

CORRECTIVE ACTION

Inspections and quality control procedures have been given added emphasis. The valve packages on LM-3 and LM-4 have been replaced with packages with improved workmanship and techniques on the terminal connectors. These improved techniques have been implemented on subsequent engines during assembly at the vendor's plant.

REFERENCES

A more detailed discussion of the analyses and tests is contained in a report by Grumman Aircraft Engineering Corporation (Report no. LED 541-2, titled *LM-1 Descent Engine Shutoff Valve Mismatch*, dated December 5, 1968.

A report concerning the quality control problems mentioned was transmitted by letter from Paul R. Wenrich, DCASR QAR, TRW, LEM Project Manager to the NASA Resident Apollo Spacecraft Project Office, Grumman Aircraft Engineering Corporation. The report is titled *Special Report on LEMDE Shutoff Valves, P/N C104619, and Shutoff Valve Actuator, Whittaker P/N 170637*, dated February 27, 1968.

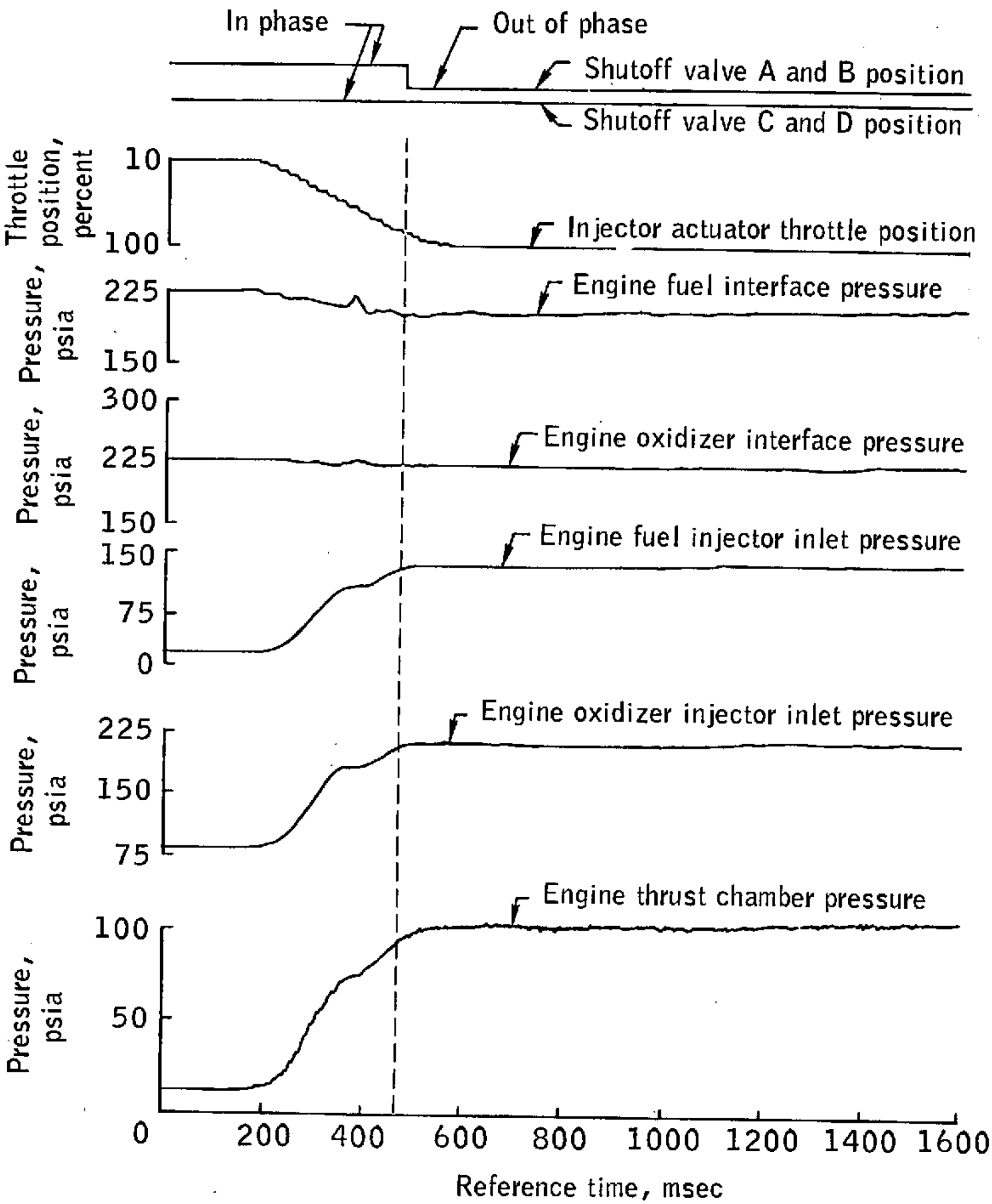


Figure 1.- Descent propulsion parameters during transition from 10-percent throttle to full throttle. (Typical of second and third firings).

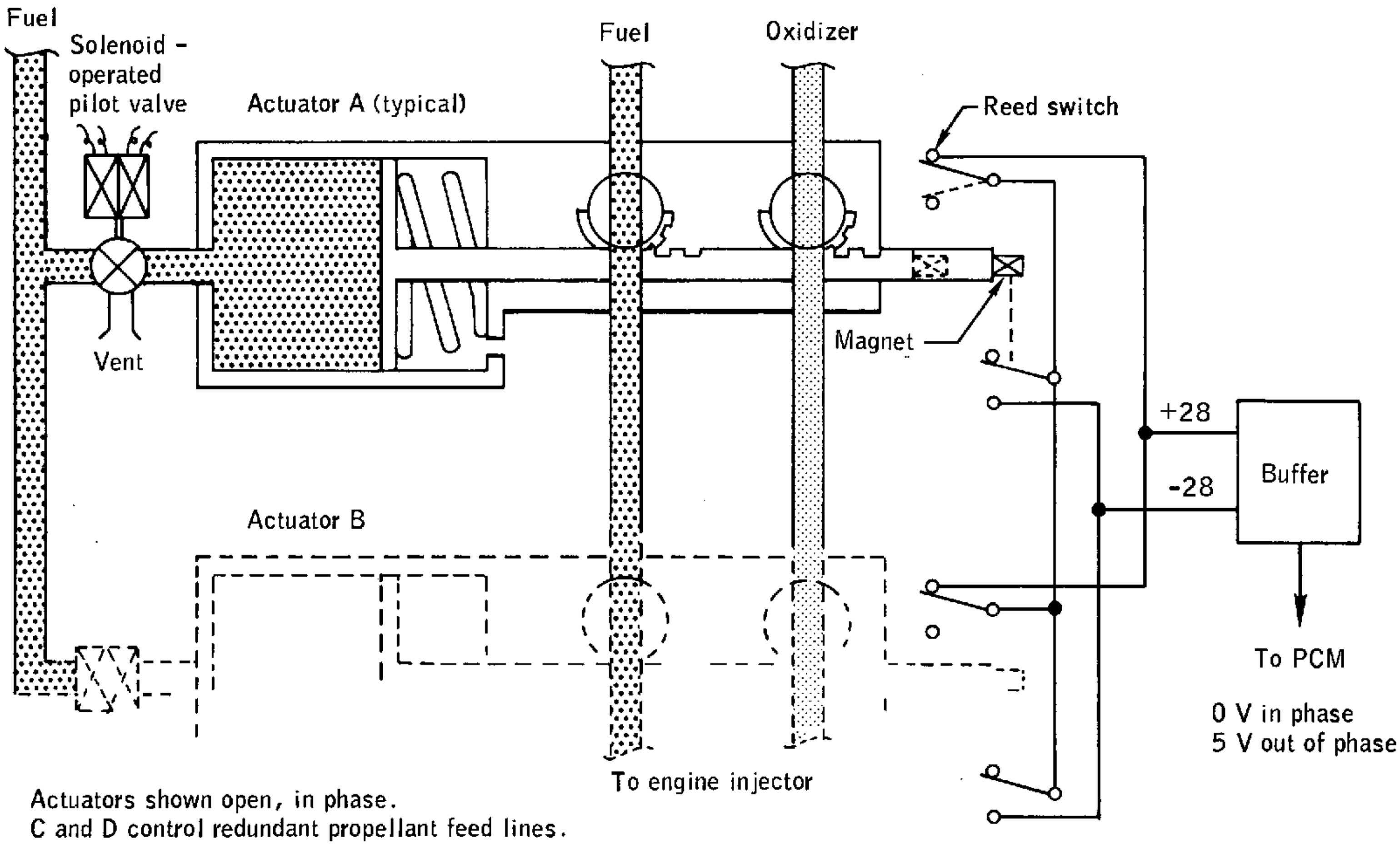
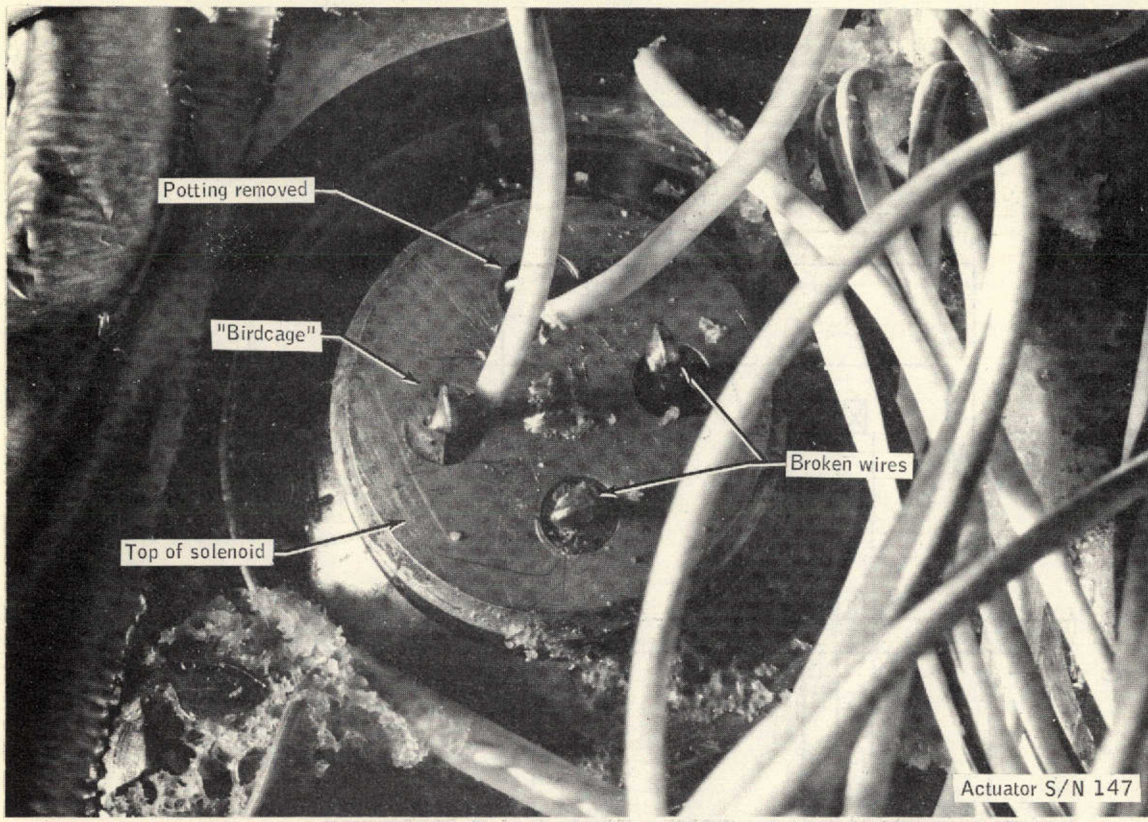


Figure 2.- Ball shutoff valves.



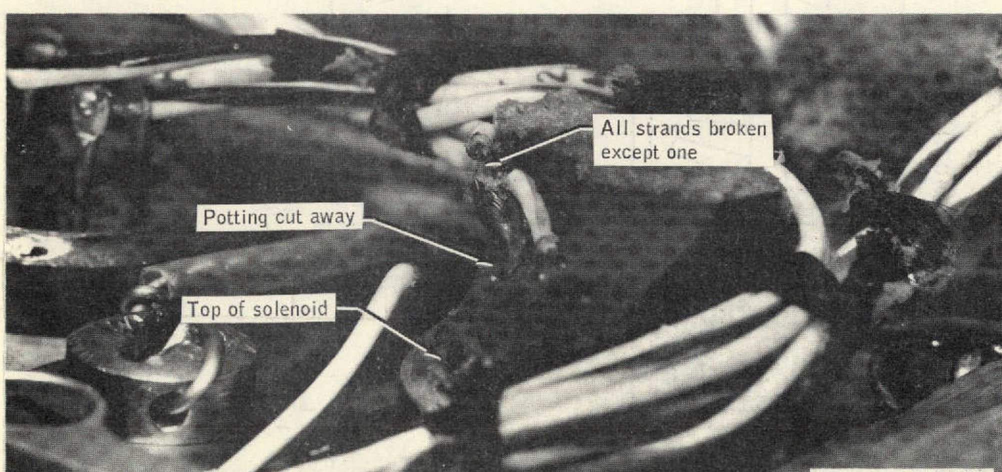


Figure 4.- Quality control problems at wiring interface with solenoid valve actuator.

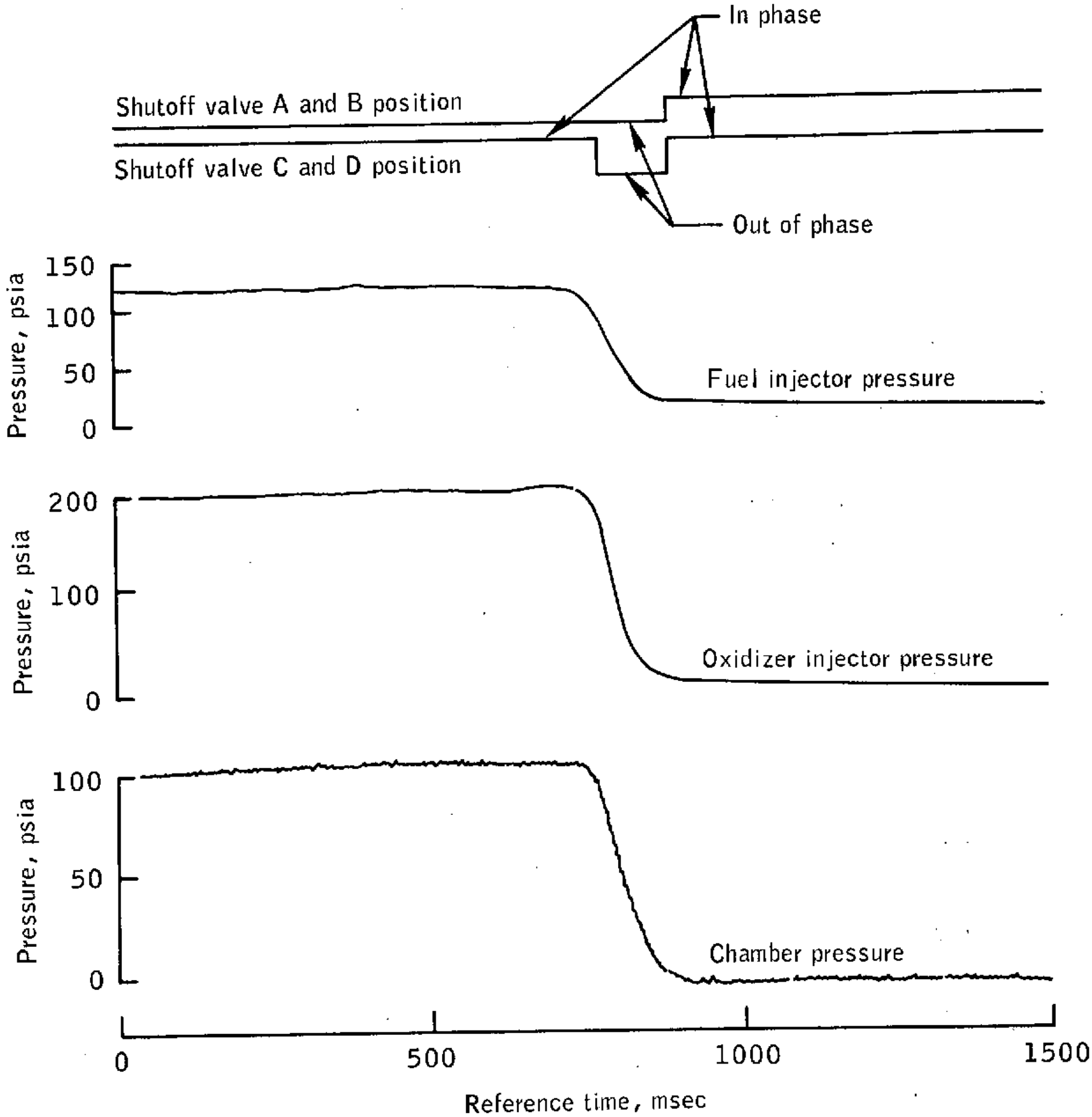


Figure 3.- Descent propulsion parameters during shutdown. (Typical of second and third firings).

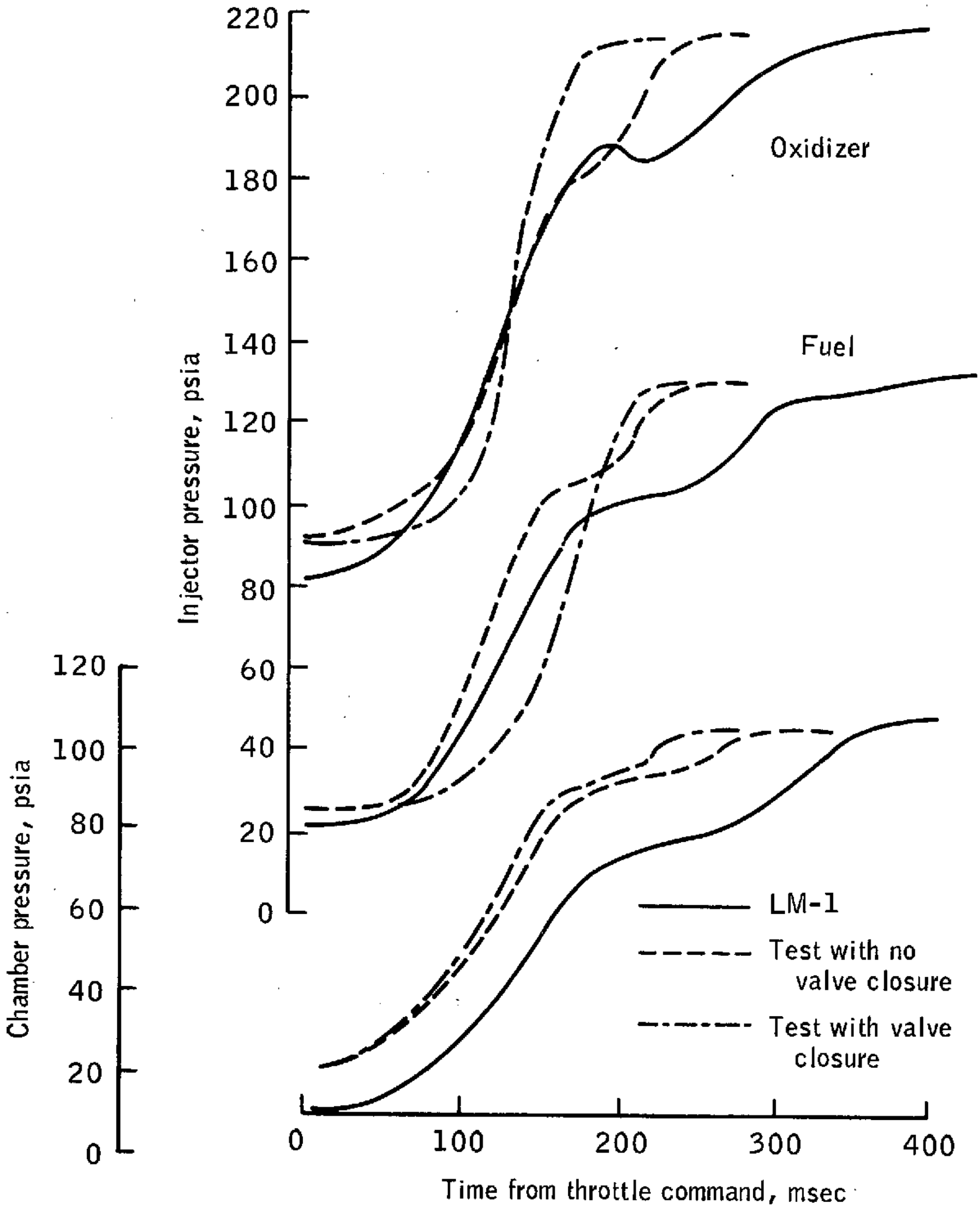


Figure 5.- Pressures during flight and ground tests.